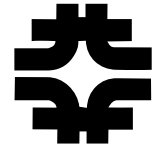


Proton Plan

Eric Prebys, FNAL Accelerator Division

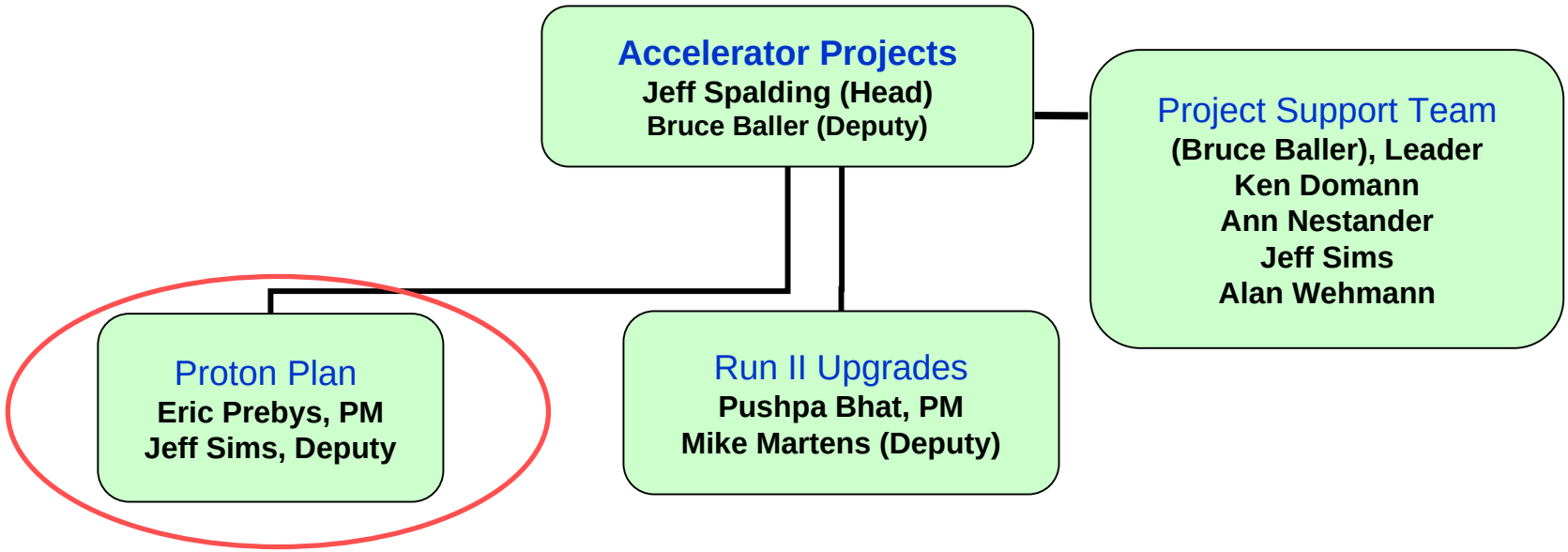
(talk given by Jeff Spalding)

Charge

- Develop a plan for a set of upgrades and operational improvements to maximize proton delivery to:
  - NuMI beamline (120 GeV from MI)
  - Booster Neutrino Beam (BNB) (8 GeV from Booster)
- Goal: complete the upgrades over the next 3 years, and operate through 2015 or beyond

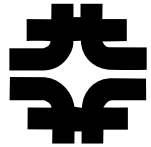
  Note: this plan precedes the Proton Driver replacement of the existing Proton Source (Linac+Booster)
- Develop the budget and timeline for these improvements
- Estimate projected proton delivery (PoT) to both beam lines

Management Organization



- Project support team:
  - Resource-Loaded Schedule (MS Project) – Domann
  - Accounting - Cobra interface to Lab's system - Nestander
  - Project management support – Sims
  - Web and documentation support - Wehmann

Context: Staged Approach to Neutrino Program



- Stage 0 (now):
  - Goal: deliver 2.5E13 protons per 2 second MI cycle to NuMI (~2E20 p/yr
  - Deliver 1-2E20 protons per year to Booster Neutrino Beam (currently MiniBooNE)
- Stage 1 (~2008):
  - A combination of Main Injector RF improvements and operational loading initiatives will increase the NuMI intensity to 4-5E13 protons per 2.2 second cycle (~3E20 p/yr)
  - This will increase by ~20% as protons currently used for pbar production become available
  - It is hoped we can continue to operate BNB at the 2E20 p/yr level during this period.
- Stage 2 (post-collider):
  - Consider (for example) using the Recycler as a preloader to the Main Injector and reducing the Main Injector cycle time
  - The exact scope and potential of these improvements are under study
- Stage 3 (proton driver)
  - Main Injector must accommodate 1.5E14 protons every 1.5 seconds
  - NuMI beamline and target must also be compatible with these intensities.

Limits to Proton Intensity

- Total proton rate from Proton Source (Linac+Booster):
  - Booster batch size
    - Typical ~5E12 protons/batch
  - Booster repetition rate
    - 15 Hz instantaneous
    - Currently 7.5Hz average (limited by injection bump and RF cooling)
  - Beam loss
    - Damage and/or activation of Booster components
    - Above ground radiation
- Total protons accelerated in Main Injector:
  - Maximum main injector load
    - Six “slots” for booster batches (3E13)
    - Up to ~11 with slip stacking (5.5E13)
    - RF stability limitations (currently ~4E13)
  - Cycle time:
    - 1.4s + loading time (1/15s per booster batch)

Operational Limit

Plan Strategy

See document: BEAMS-DOC-1441 (11/09/04) at
http://beamsdocs.fnal.gov/cgi-bin/public/DocDB/DocumentDatabase

- Increase the proton delivery from the Booster (to both NuMI and BNB)
  - Increase acceptance by improving orbit control and beam quality
  - Increase maximum average Booster repetition rate
- Increase the beam intensity in the Main Injector for NuMI
  - Main Injector multi-batch operation
  - Slip stacking in Main Injector (requires RF upgrade)
- Improve operational reliability
  - Alleviate 7835 Problem
  - Linac quad supplies
  - Booster and Linac Instrumentation
  - Booster RF Upgrade

Cost Tables from Beams-Doc-1441 (a)

TABLE 2: M&S and SWF in $K at Level 3

WBS	Description	M&S Base	M&S Cont	M&S Total	SWF Base	SWF Cont	SWF Total
1	**Proton Plan**	**16,513**	**42%**	**23,486**	**6,648**	**57%**	**10,419**
1.1	**Linac Upgrades**	**2,705**	**86%**	**5,039**	**981**	**65%**	**1,622**
1.1.1	Linac PA Vulnerability	2,000	100%	4,000	300	100%	600
1.1.2	Linac Quad Power Supplies	617	50%	925	628	50%	942
1.1.3	Linac Instrumentation Upgrade	88	30%	114	53	50%	80
1.2	**Booster Upgrades**	**6,499**	**35%**	**8,765**	**2,777**	**54%**	**4,262**
1.2.1	Determine Rep Rate Limit	0	0	0	110	50%	165
1.2.2	ORBUMP System	256	42%	364	231	47%	338
1.2.3	Corrector System	629	58%	995	715	57%	1,124
1.2.4	30 Hz Harmonic	1,031	35%	1,388	279	60%	447
1.2.5	Gamma-t System	0	0	0	50	100%	100
1.2.6	Alignment Improvements	0	0	0	60	50%	90
1.2.7	Drift Tube Cooling	10	50%	15	10	50%	15
1.2.8	Booster RF Cavity #20	300	50%	450	120	50%	180
1.2.9	Booster Solid State RF PA's	4,200	30%	5,460	960	50%	1,440
1.2.10	Booster Instrumentation	73	27%	93	242	50%	363
1.3	**Main Injector Upgrades**	**7,294**	**32%**	**9,661**	**2,026**	**60%**	**3,239**
1.3.1	Large Aperture Quads	194	50%	291	406	50%	609
1.3.2	Main Injector Collimator	200	100%	400	150	100%	300
1.3.3	NUMI Multi-batch Operation	0	0	0	250	100%	500
1.3.4	Main Injector RF Upgrade	6,900	30%	8,970	1,220	50%	1,830
1.4	**Management**	**15**	**32%**	**20**	**864**	**50%**	**1,296**

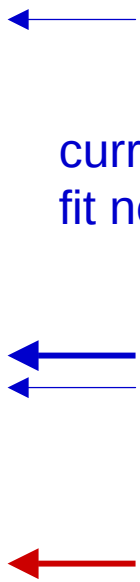
46% contingency in M&S+SWF
Dominated by M&S (esp RF parts)

WBS is aligned to AD Organization by Accelerator

Cost Tables from Beams-Doc-1441 (b)

TABLE 3: Total cost (M&S and SWF) by fiscal year.

WBS	Description	Base Estimate: M&S and SWF				Total with Contingency
		FY05	FY06	FY07	Total	
1	**Proton Plan**	**8,341**	**10,965**	**3,854**	**23,161**	**33,904**
1.1	**Linac Upgrades**	**1,039**	**2,097**	**550**	**3,686**	**6,661**
1.1.1	Linac PA Vulnerability	650	1,100	550	2,300	4,600
1.1.2	Linac Quad Power Supplies	248	997	0	1,245	1,867
1.1.3	Linac Instrumentation Upgrade	141	0	0	141	194
1.2	**Booster Upgrades**	**1,945**	**4,718**	**2,613**	**9,276**	**13,027**
1.2.1	Determine Rep Rate Limit	110	0	0	110	165
1.2.2	ORBUMP System	486	0	0	486	702
1.2.3	Corrector System	583	761	0	1,344	2,119
1.2.4	30 Hz Harmonic	146	1,165	0	1,310	1,835
1.2.5	Gamma-t System	50	0	0	50	100
1.2.6	Alignment Improvements	30	30	0	60	90
1.2.7	Drift Tube Cooling	20	0	0	20	30
1.2.8	Booster RF Cavity #20	420	0	0	420	630
1.2.9	Booster Solid State RF PA's	0	2,680	2,480	5,160	6,900
1.2.10	Booster Instrumentation	100	82	133	315	456
1.3	**Main Injector Upgrades**	**5,010**	**3,860**	**450**	**9,320**	**12,900**
1.3.1	Large Aperture Quads	600	0	0	600	900
1.3.2	Main Injector Collimator	250	100	0	350	**700**
1.3.3	NUMI Multi-batch Operation	50	150	50	250	500
1.3.4	Main Injector RF Upgrade	4,110	3,610	400	8,120	**10,800**
1.4	**Management**	**348**	**290**	**241**	**879**	**1,316**



currently redefining scope to fit new budget guidance

Current Budget Guidance

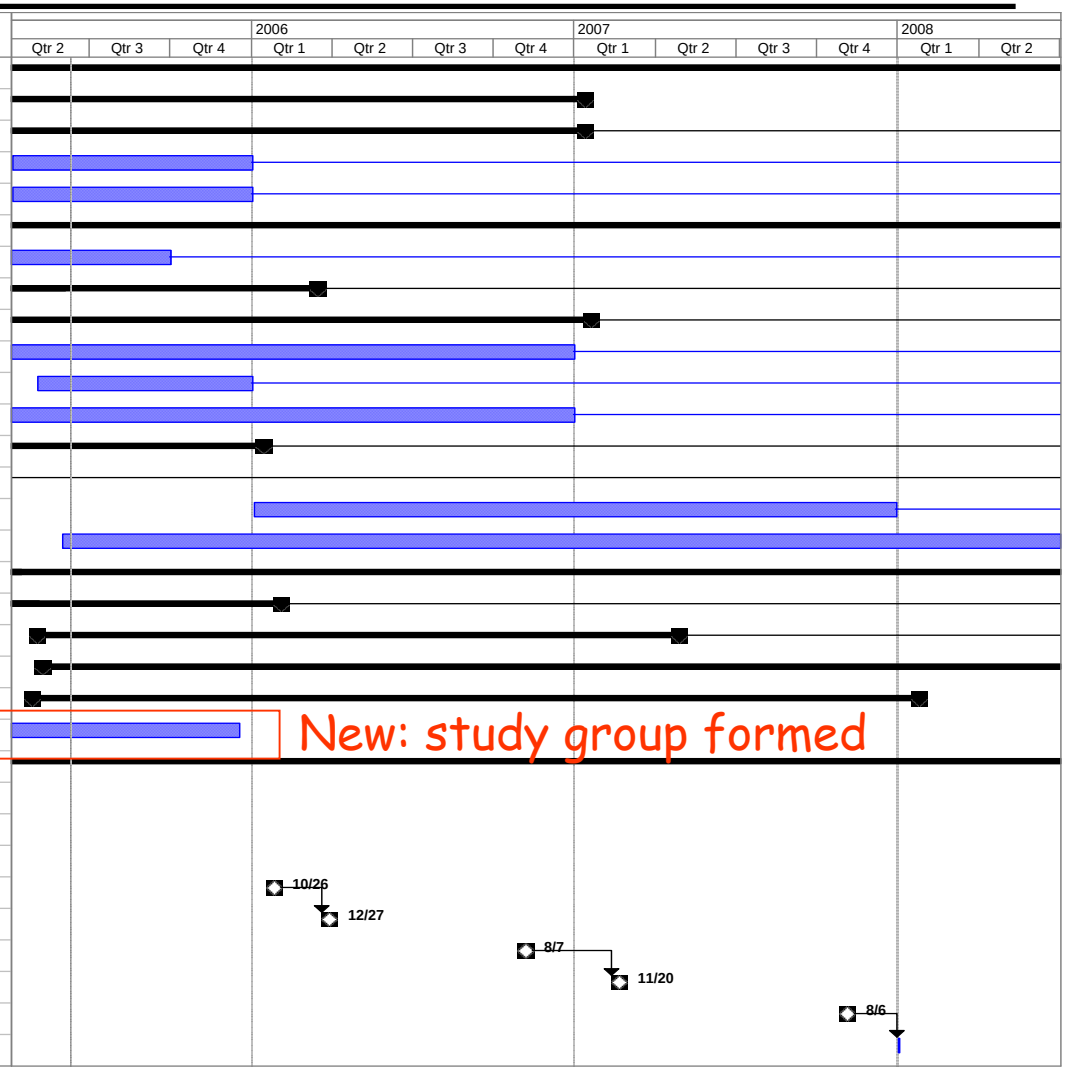
- After the cancellation of BTeV, we have the following budget guidance (M&S+SWF):

	FY05	FY06	FY07	FY08	Total
Present Guidance	7327	7845	6915	6116	28203

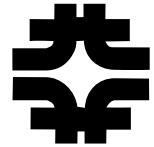
- Most Likely Scenario
  - Main Injector RF project and Booster Corrector System get delayed by one year, relative to the original plan
  - Booster RF Solid State PA upgrade deferred indefinitely

Present Plan
(draft - not fully rescoped)

Uniq	WBS	Name
1	**0**	**Proton Plan**
2	**1**	**Linac Upgrades**
6	**1.1**	**Linac PA Vulnerability**
7	1.2	Linac Instrumentation Upgrade
8	1.3	Linac Quad Power Supplies
3	**2**	**Booster Upgrades**
9	2.1	Determine Rep Rate Limit
10	**2.2**	**OrBump System**
11	**2.3**	**Corrector System**
12	2.4	30 Hz Harmonic
13	2.5	Gamma-t System
14	2.6	Alignment Improvements
15	**2.7**	**Drift Tube Cooling**
16	**2.8**	**Booster RF Cavity #20**
17	2.9	Booster Solid State RF PAs
18	2.10	Booster Instrumentation
4	**3**	**Main Injector Upgrades**
19	**3.1**	**Large Aperture Quads**
20	**3.2**	**Main Injector Loss Mitigation**
21	**3.3**	**NuMI Multibatch Operation**
22	**3.4**	**Main Injector RF Upgrade**
202	5	Recycler Preloader Working Group
5	**4**	**Management**
23	4.1	Completion of Phase A
24	4.2	Completion of Phase B
25	4.3	Completion of Phase C
59	4.4	Start 2005 Shutdown
81	4.5	Finish 2005 Shutdown
79	4.6	Start 2006 Shutdown
80	4.7	Finish 2006 Shutdown
82	4.8	Start 2007 Shutdown
83	4.9	Finish 2007 Shutdown



Resource-Loaded Schedule
Cost and Schedule Reporting



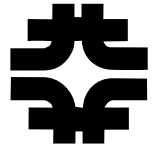
Building resource loaded schedule:

- For several L3 projects the work is already ongoing (TD is building Orbump, large aperture quads…)
  - Budget codes established and capturing costs
- Scope under development for some L3 projects (eg. MI RF upgrade: prototype phase, then review and production phase)
  - Developing strategy, milestones, and decision points
  - Will include estimates with large contingency as place-holders where necessary

Will use the same cost and schedule reporting tools as the Run II Upgrades

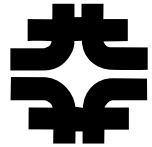
- Reporting via monthly PMG
- Change control similar to Run II Upgrades

Status of Major Work



- Linac (1)
  - (1.1) 7835 Task force
    - Working with vendor (Burle)
    - Placed order for 12 extra spare tubes (two year supply) over the next two years
    - Studying lifetime issues (filament current, etc)
    - Formulating replacement plan
  - (1.3) Low Energy Linac (LEL) quad power supplies
    - Working on prototype, based on HEL supplies
- Booster (2)
  - (2.2) ORBUMP System
    - Magnets - First magnet built and tested, proceeding with the rest
    - Power Supply - Procuring and assembling
  - (2.3) Corrector System
    - Conceptual design complete for the corrector magnets, working on detailed design
    - Working on power supply specs
  - (2.4) 30 Hz Harmonic in Booster cycle
    - Work Proceeding on Prototype

Status of Major Work (cont'd)



- (3) Main Injector
  - (note that the BLM/BPM upgrades are under the Run II)
  - (3.1) Large Aperture Quads
    - In fabrication. Will be ready for 05 shutdown
  - (3.2) Loss mitigation/collimator system
    - Working group formed
    - Identifying collimator candidates for MI-8
    - Starting ring collimator system design based on Booster system
  - (3.3) Multi-batch operation
    - Demonstrated mixed mode (2+5) operation w/ 5 batches of 2E12 to NuMI (goal For FY05 is 5 batches of 5E12)
    - Developing schemes for slip-stacking and barrier stacking
  - (3.4) Main Injector RF Upgrade

Main Injector Loading

- Initial NuMI operation (“2+5”):
  - Two batches are slip stacked for antiproton production
  - Five more batches loaded for NuMI
  - All are accelerated together
- Ultimate NuMI operation (“2+9”):
  - Five batches will be loaded into the Main Injector, leaving one empty slot
  - Six more batches will be loaded and slipped with the first to make two for antiproton production and 9 for NuMI
  - This will exceed the capacity of the current RF system

Main Injector RF

- The present MI RF system:
  - Number of cavities: 18
  - Total Power Available: 175 kW/cavity (single PA)
  - Total Power dissipated: 58.6 kW/cavity
  - Power available for acceleration: 116.4 kW/cavity
  - Maximum acceleration rate: 200 GeV/s
- In the absence of beam loading compensation, an RF system is stable until the energy expended in accelerating the beam is *equal* to the energy dissipated in the cavity.
- Feed forward loops can increase this stability threshold
- For the present system
  - Maximum guaranteed stable intensity: 3.3E13 protons
  - With feed-forward 4E13 is likely
  - Power limited intensity: 6.5E13 protons

Options

- By adding an additional 28.9 kW passive load to each cavity, we could ensure 87.5 kW of power for stable acceleration
  - Limit ~ 4.9E13 protons/load
  - Cost scale ~$2M
- Each cavity has an additional port for a second PA, allowing an additional 350 kW of total power
  - Limit ~ 9.8E13 protons/load in the most conservative case (175 kW power dissipation)
  - Possibly higher with feedback loops
  - Cost scale ~$12M

Main Injector RF in FY05 (3.4)

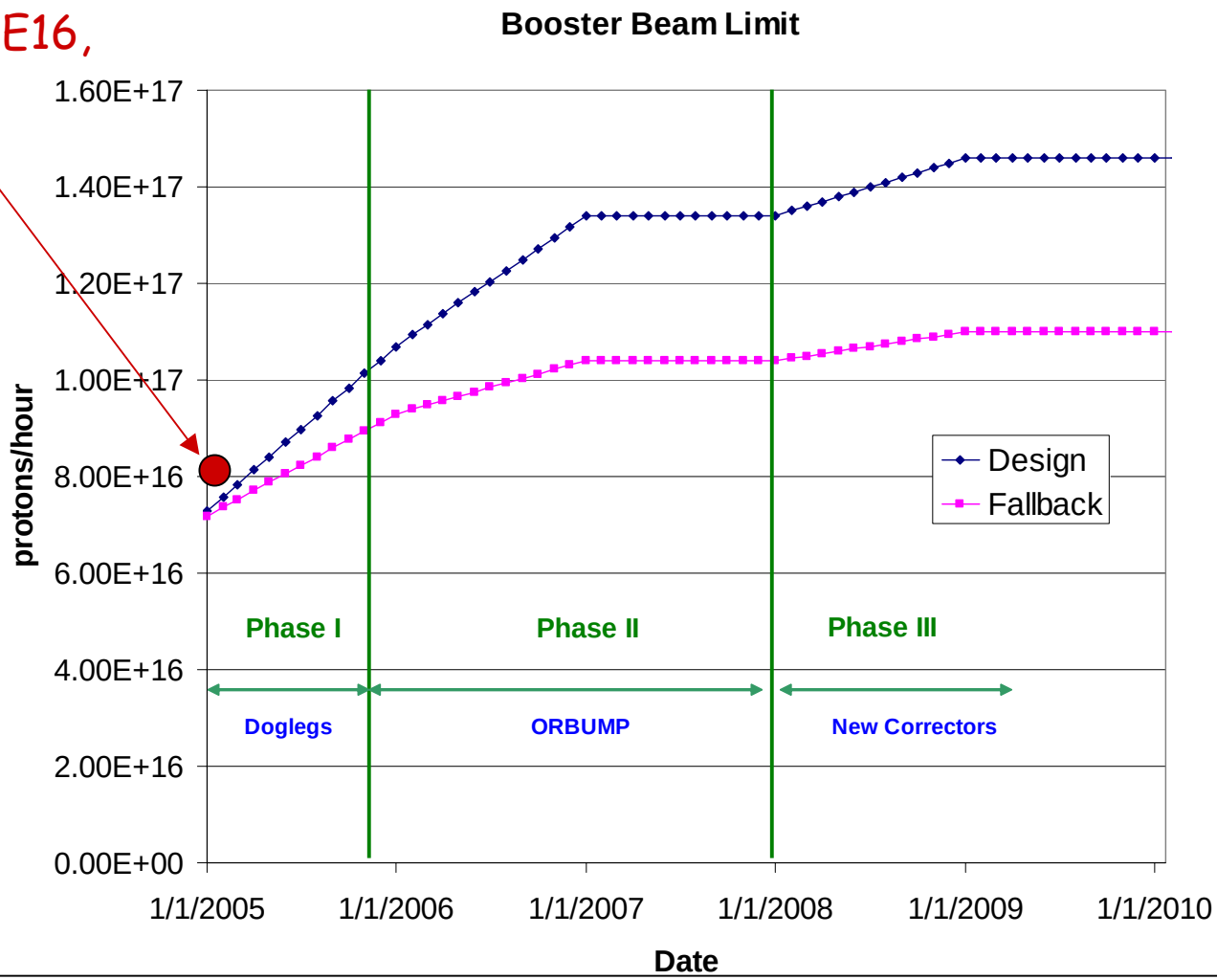
- Build prototype cavity from existing spare
  - Passive load
    - Existing port or cut new one?
  - Second PA
    - Requires new modulator, other parts exist
- Carry out a series of studies in the Main Injector
  - Determine effectiveness of feed-forward loops
  - Determine optimal passive load and predict intensity limit for one- and two PA scenarios
- Refine cost estimate for passive load and PA upgrades
- Use this information to develop and review long range plan (beginning 2006)

Proton Projections

- Phases of Operation
  - Phase I (now)
    - Booster lattice distortions ameliorated
    - Booster limited to 7.5Hz total repetition rate
    - Main Injector limited to 4E13 protons (2+5 operation)
  - Phase II (after 2005 shutdown)
    - Injection bump (ORBUMP) replaced
    - Drift tube cooling in Booster RF cooling finished
    - Booster capable of 8-9Hz operation
    - MI still limited to 2+5 operation
  - Phase III (after 2007 shutdown)
    - MI RF upgrade complete
    - 2+9 operation to NuMI

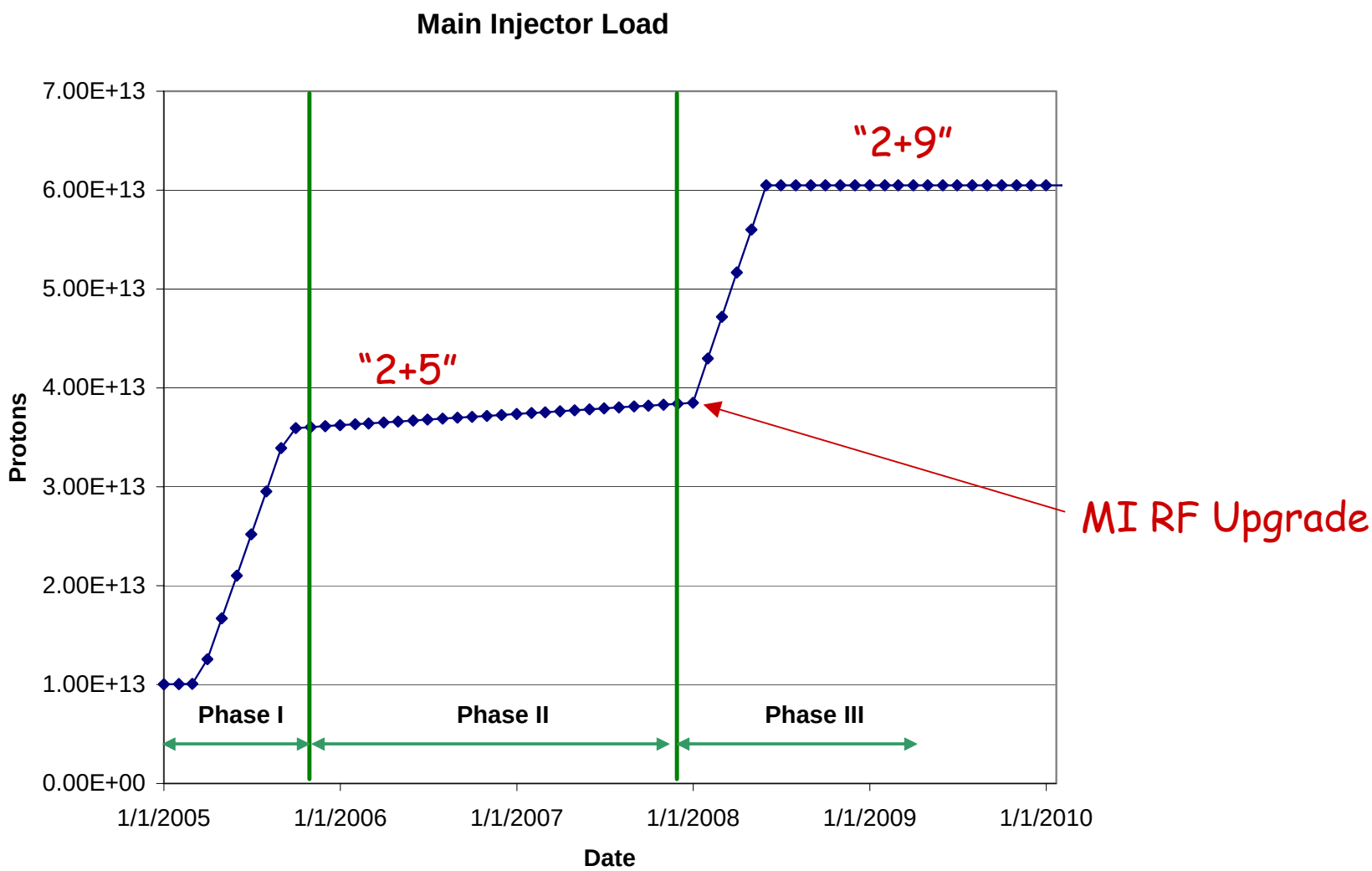
Predicted Peak Proton Intensity Limits

Demonstrated >8E16, typical ~7E16



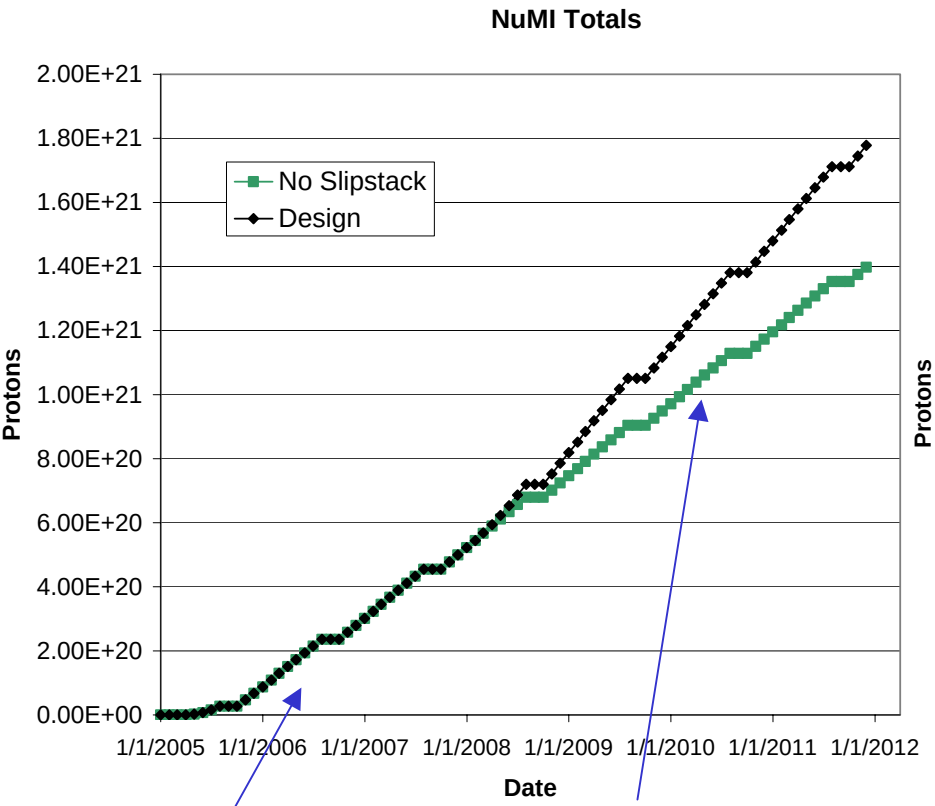
See document for details

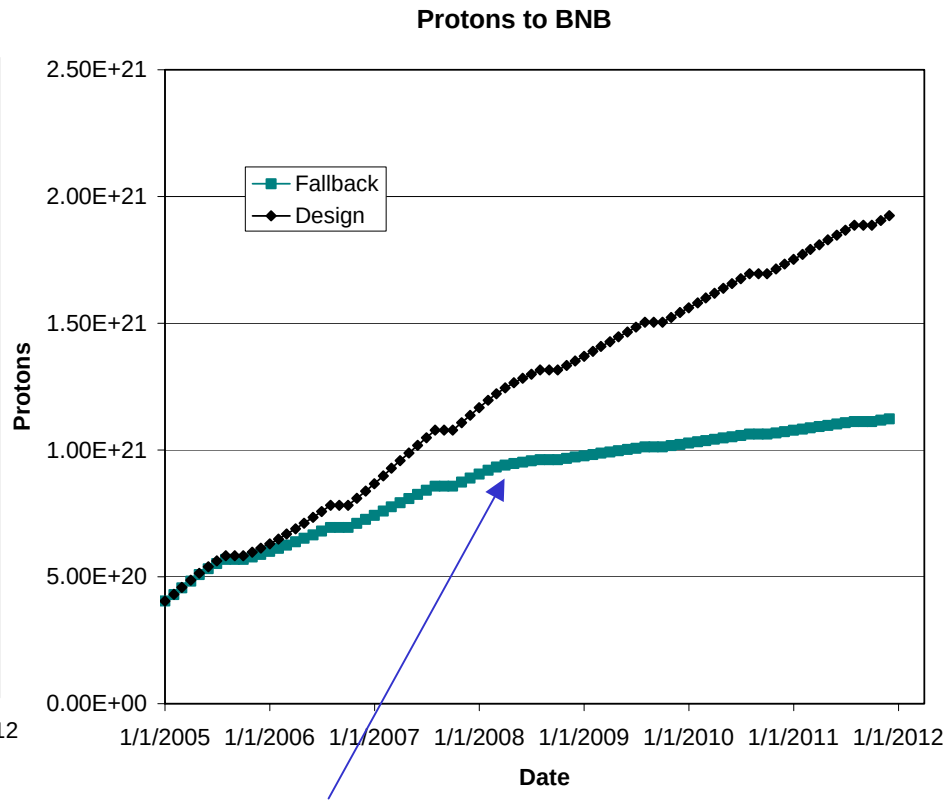
Main Injector Loading



Long Term Projections
(~"delayed" scenario in document)

(for FY05 projections see McGinnis Talk)





This turn-on is slower than in document

NuMI fallback = slip-stacking fails

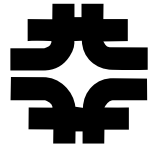
BNB fallback = poor performance of Booster aperture upgrades

BNB only runs during shot setup

“Design” PoT from the document

	Booster Batch Size	Main Injector Load	Cycle Time	MI Intensity	Booster Rate*	Total Proton Rate	Annual Rate at end of Phase	
		(AP + NuMI)	(sec)	(protons)	(Hz)	(p/hr)	NuMI	BNB
Actual Operation								
July, 04	5.0E+12	1+0	2.0	0.5E+13	5.1	0.8E+17	0	3.3E+20
Proton Plan								
Phase I	5.10E+12	2+1→2+5	2.0	3.6E+13	6.3	1.0E+17	2.0E+20	1.5E+20
Phase II	5.3E+12	2+5	2.0	3.7E+13	7.5	1.2E+17	2.2E+20	2.8E+20
Phase III	5.50E+12	2+9	2.2	6.0E+13	8.3	1.5E+17	3.4E+20	2.2E+20
Beyond Scope of Present Plan								
11 Hz	5.50E+12	2+9	2.2	6.1E+13	11.0	2.0E+17	3.4E+20	5.0E+20

Summary



- The Proton Plan encompasses accelerator improvements to maximize protons to NuMI and the 8 GeV line over the next 10 years
- The implementation of the Plan will provide
  - ~7E16 p/hr to NuMI (~3E20 p/yr)
  - Up to ~4E16 p/hr (1-2E20 p/yr) for the 8 GeV line
- We are studying concepts for further improvements in the post collider era (for example using the Recycler as a preloader)
- A Resource-loaded schedule and cost and schedule tracking system are in development